

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2247

A COMPARISON OF THE LATERAL CONTROLLABILITY WITH FLAP
AND PLUG AILERONS ON A SWEEPBACK-WING
MODEL HAVING FULL-SPAN FLAPS

By Powell M. Lovell, Jr.

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SUMMARY

A free-flight-tunnel investigation has been made to compare the dynamic lateral control characteristics provided by step plug ailerons with those provided by conventional flap ailerons on a sweptback-wing model having full-span flaps. The model had a 38° sweptback wing with an aspect ratio of 3 and a taper ratio of 0.5. The static stability and control characteristics of the flight-test model were determined from force tests and the time-lag characteristics of the ailerons were determined from stand tests in which there was freedom only in roll. The data from these force tests were used to determine the flight-test conditions. The flight tests of the model were made over a range of lift coefficient from 1.0 through the stall.

For flights during which the oscillatory (Dutch roll) stability was adequate, the controllability of the model was more satisfactory with plug ailerons alone than with flap ailerons alone because the loss of rolling effectiveness caused by the large adverse yawing moments of the flap ailerons was more objectionable than the lag of the plug ailerons. The controllability of the model was generally satisfactory over the entire flight test range for control with plug ailerons alone or with flap ailerons and rudder.

For flights during which the stability of the Dutch roll oscillation was inadequate, the flap ailerons alone afforded a better control than either plug ailerons alone or flap ailerons and rudder up to a lift coefficient of 1.7, apparently because the lightly damped oscillation was more easily excited by controls when the adverse yawing moment was reduced.

INTRODUCTION

Recent research has indicated that spoilers may offer several advantages over conventional flap ailerons for lateral control with sweptback wings. Some of these advantages are: greater rolling moments at high angles of attack; favorable, or less adverse, yawing moments; higher aileron reversal speeds due to smaller wing twisting moments; the possibility of smaller control forces; and the possibility of using a simple configuration of full-span lift flaps. Investigations to determine the static control characteristics of various spoiler configurations on swept wings have been made by the National Advisory Committee for Aeronautics (for example, reference 1). In order to determine the dynamic control characteristics of spoiler ailerons on sweptback wings in the flap-retracted condition, an investigation (reference 2) was made in the Langley free-flight tunnel with a flying model having the optimum spoiler-plan-form configuration determined from the tests reported in reference 1. The present investigation was made in the Langley free-flight tunnel as a continuation of the investigation reported in reference 2 to include the flap-extended condition.

The model used in the present investigation had a 38° sweptback wing with an aspect ratio of 3 and a taper ratio of 0.5. The model was equipped with full-span duplex flaps and with both flap ailerons and step plug ailerons. The investigation consisted mainly of flight tests over a range of lift coefficient from 1.0 through the stall to obtain a comparison of the controllability of the model with the two types of ailerons. Tests to determine the time lag from full control deflection to maximum rolling acceleration were made with the model mounted on a stand that allowed freedom only in roll. Force tests were made to determine the static stability and control characteristics of the model for the purpose of establishing the flight-test conditions.

SYMBOLS

The forces and moments are referred to the stability axes which are defined as an orthogonal system of axes intersecting at the airplane center of gravity in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. A diagram of these axes showing the positive direction of forces and moments is presented in figure 1.

m	mass of model, slugs
S	wing area, square feet

b	wing span, feet
c	wing chord, feet
$\bar{c}$	wing mean aerodynamic chord, feet
k_x	radius of gyration of model about X body axis, feet
k_y	radius of gyration of model about Y body axis, feet
k_z	radius of gyration of model about Z body axis, feet
ψ	angle of yaw, degrees
V	airspeed, feet per second
ρ	mass density of air, slugs per cubic foot
q	dynamic pressure, pounds per square foot ($\rho V^2/2$)
α	angle of attack of wing, degrees
β	angle of sideslip, degrees ($-\psi$)
ϕ	angle of bank, degrees
$\dot{\phi}$	rolling angular velocity, degrees per second
$\ddot{\phi}$	rolling angular acceleration, degrees per second per second
C_L	lift coefficient (Lift/qS)
C_D	drag coefficient (Drag/qS)
C_Y	lateral-force coefficient (Y/qS)
C_m	pitching-moment coefficient ($M/qS\bar{c}$)
C_l	rolling-moment coefficient (L/qSb)
C_n	yawing-moment coefficient (N/qSb)
Y	lateral force, pounds
M	pitching moment, foot-pounds
L	rolling moment, foot-pounds
N	yawing moment, foot-pounds

$C_{Y\beta}$	rate of change of lateral-force coefficient with angle of sideslip per degree ($\partial C_Y / \partial \beta$)
$C_{l\beta}$	rate of change of rolling-moment coefficient with angle of sideslip per degree ($\partial C_l / \partial \beta$)
$C_{n\beta}$	rate of change of yawing-moment coefficient with angle of sideslip per degree ($\partial C_n / \partial \beta$)
δ_{aflap}	total aileron deflection of flap ailerons (summation of equal up and down deflection); degrees
δ_{aplug}	projection of plug ailerons above upper surface of wing, percent chord
δ_r	rudder deflection, degrees
Subscript:	
max	maximum; indicates maximum available for particular test condition

APPARATUS

The investigation was conducted in the Langley free-flight tunnel which is equipped for testing free-flying dynamic models. A complete description of the tunnel and its operation for testing models in free flight and by force tests is given in references 3 and 4, respectively.

A three-view sketch of the model used in the present investigation is presented in figure 2. The model was the same as that used in the investigation of reference 2 except for the addition of flaps, a proportional control system, and more negative wing incidence. The model had the following geometric and mass characteristics:

Wing area, square feet	6.75
Span, feet	4.50
Sweepback of quarter-chord line, degrees	38.00
Aspect ratio	3.00
Taper ratio	0.50
Mean aerodynamic chord, feet	1.50
Center-of-gravity location, percent mean aerodynamic chord	0.25
Airfoil section	Rhode St. Genese 35
Mass, m, slugs	0.838
Nondimensional radius of gyration about	
X body axis, k_x/b	0.195
Nondimensional radius of gyration about	
Y body axis, k_y/b	0.369
Nondimensional radius of gyration about	
Z body axis, k_z/b	0.405

These mass characteristics were not measured for the present investigation, but, since the only significant changes made to the model for the present investigation were the addition of flaps and a more negative incidence to the wing which changed the inclination of the longitudinal principal axis of inertia, the mass characteristics were believed to be approximately the same as those of the original model which were given in reference 2. The additional negative wing incidence (a total of -10°) was incorporated in the model of the present investigation in order to improve the oscillatory stability characteristics so that the pilot's opinion of the controllability would not be influenced by the low oscillatory stability of the model. All the results presented herein were obtained from tests made with -10° incidence. A discussion of the effects of wing incidence on the oscillatory stability appears in a subsequent section.

The wing had half-span, 20-percent-chord, flap ailerons and 60-percent-semispan step plug ailerons. These step plug ailerons consisted of six segments, perpendicular to the plane of symmetry of the model. The span of each segment was 0.10 semispan, and the center of each segment was on the 0.70-chord line. This plug-aileron configuration was determined as the optimum from the tests reported in reference 1. Each segment of the plug ailerons fitted into a slot in the wing in such a way that the slot was closed when the aileron was in the retracted or neutral position and open when the aileron was projected above the upper surface of the wing. A cross section of the wing giving details of the plug ailerons is shown in figure 2. The maximum extension of the plug ailerons was 0.06 of the local chord.

The full-span flap configuration was selected on the basis of providing maximum lift for the model while still allowing the use of the flap ailerons. The full-span duplex flap configuration is shown in figure 2. It consisted of 0.44-semispan 0.20-chord extensible split flaps inboard of the flap ailerons (section A-A, fig. 2) and 0.56-semispan 0.20-chord balanced split flaps behind and below the flap-aileron trailing edge (section B-B, fig. 2). Both portions of the flap were deflected 50° . The outboard flap was so arranged that the flap ailerons could be deflected a maximum of 20° down. Thus, the flap ailerons in combination with the balanced split flap were effectively slot-lip ailerons.

A proportional control system was used on the model during the present series of flight tests instead of the flicker system used in the previous investigation reported in reference 2. With the proportional control system the amount of control applied to the model was regulated by the magnitude of the control deflection as well as the length of time the deflection was applied. With the flicker system, the control was either neutral or at maximum deflection in one direction or the other; and during any one particular flight, the maximum deflection was fixed and the amount of control applied to the model was regulated

by the length of time the control was held deflected. The control system was arranged so that lateral control of the model could be obtained through use of either the flap ailerons or the plug ailerons and the change from one type of control to the other could be effected in flight so that a direct comparison could be made of the controllability provided by the two types of controls. The rudder could be used with either of the aileron control systems or could be held fixed in a trim position during flight.

DETERMINATION OF STATIC STABILITY AND CONTROL

CHARACTERISTICS OF FLIGHT-TEST MODEL

Force tests were made at a dynamic pressure of 1.5 pounds per square foot to determine the static lateral stability and control characteristics of the model for the purpose of establishing the flight-test conditions. The aileron-control characteristics were determined for an angle-of-attack range for maximum projection of the plug ailerons and for 20° up and 20° down deflections of the left flap aileron. The rudder-control characteristics were measured so that in the flight tests the rudder deflection could be adjusted to make the yawing moments of the combination of flap aileron and rudder equal to those of the plug ailerons alone or to make the yawing moments of the combination of either aileron and rudder equal to zero. The rudder-control characteristics were determined for an angle-of-attack range for rudder deflections of 5° , 10° , and 15° . The static-lateral-stability derivatives of the model were determined from measurements of force and moment coefficients at 5° and -5° yaw.

The results of the force tests are presented in figures 3 to 6. The dashed curves of figures 3 to 6 show the results of force tests made on the same model for the flap-retracted condition taken from reference 2. Figures 3 and 4 show the static longitudinal and lateral stability characteristics of the model with all the controls neutral. Figure 5 shows the static lateral control characteristics of the plug ailerons at maximum projection. Figure 6 shows the static lateral control characteristics of the flap ailerons for a 40° total deflection. Figures 5 and 6 show that the aileron control effectiveness of the plug ailerons increased with increase in lift coefficient, whereas the aileron control effectiveness of the flap ailerons decreased with increase in lift coefficient. The adverse yawing moments of both types of ailerons generally increased with increase in lift coefficient, and at all lift coefficients the adverse yawing moments of the flap ailerons were much larger than those of the plug ailerons. The fact that the flap-aileron control effectiveness is much greater for the flap-extended condition than for the flap-retracted condition, as shown in figure 6, is also illustrated in reference 5 which shows similar results for straight wings.

Comparison of the data of figures 5 and 6 shows that the flap ailerons could produce much larger rolling moments than the plug ailerons (for full projection) at all angles of attack. The rolling moments obtained from plug ailerons could be increased, however, by using larger plug-aileron projections than were possible with the present model.

DETERMINATION OF TIME-LAG CHARACTERISTICS OF THE FLIGHT-TEST MODEL

Measurements of the time lag from full control deflection to maximum acceleration for the two types of ailerons were made with the model mounted on a stand at an angle of attack of 10° and free to roll about the longitudinal body axis. For these tests, the deflection of the flap ailerons was adjusted to give about the same static rolling moment as was obtained by maximum projection of the plug ailerons. Motion-picture records taken at 128 frames per second were made of both right and left rolls with the flap ailerons and the plug ailerons. Control position and angle of bank were read directly from these records. Curves of rolling velocity and acceleration were obtained by taking slopes of the angle-of-bank curves to obtain rolling velocity and of the rolling-velocity curves to obtain rolling acceleration. Figure 7 shows typical time histories of the rolling motions of the model. These data indicate that the flap ailerons produced maximum acceleration almost at the same time that full deflection was reached but that the plug ailerons produced maximum acceleration about 0.17 second after full deflection was reached. The curve for the plug ailerons shows, however, that the rolling acceleration built up rapidly initially so that it reached approximately one-half the maximum value by the time the controls reached full deflection.

On the same model with flaps retracted (reference 2) the plug ailerons were also found to have greater lag than the flap ailerons, but the difference between the two time lags was of a somewhat smaller magnitude. The larger time lag of the plug ailerons when used with this type of full-span flap may be explained by the fact that the effective chord became longer and the location of the plug ailerons was therefore forward of the 0.70-chord line when the flaps were extended. This result might be expected since the data of reference 6 indicate that on unswept wings more forward chordwise locations of spoiler ailerons result in more lag than rearward locations.

If the model is considered a $\frac{1}{10}$ -scale model of an airplane, the lag measurements indicate that the airplane would require less than 0.1 second to reach maximum rolling acceleration with flap ailerons and would require about 0.5 second to reach maximum rolling acceleration with plug

ailerons. Comparison of these scaled-up values of time lag with the lag requirements of reference 7 indicates that the flap ailerons would easily satisfy the requirements but that the plug ailerons would not satisfy the requirements.

SCOPE OF FLIGHT TESTS

Flight tests of the model were made over a range of lift coefficient from 1.0 through the stall. At each test lift coefficient and at the stall, flights were made with the following control combinations for the rolling-moment and yawing-moment conditions indicated:

$\left(C_{l_{flap}}\right)_{\max }=\left(C_{l_{plug}}\right)_{\max }$					$\delta_{aflap}=30^{\circ}$	
Ailerons alone		Ailerons and rudder			Ailerons alone	Ailerons and rudder $\left(C_{n_{flap}}=0\right)$
		$C_{n_{flap}}=C_{n_{plug}}$	$C_{n_{flap}}=0=C_{n_{plug}}$			
Plug ailerons	Flap ailerons	Flap ailerons	Flap ailerons	Plug ailerons		

The maximum deflections available for each flight condition and the rolling and yawing moments produced by these deflections are shown in figure 8 for the range of lift coefficient covered in the flight tests. The deflections for the flap ailerons were obtained from the data of figure 6 by assuming a linear variation of rolling and yawing moments with aileron deflection. Preliminary tests indicated that the variation was very nearly linear. The use of the proportional control system made it possible for the pilot to deflect either of the ailerons less than the maximum allowable deflection. Therefore, smaller deflections than the maximum were sometimes used because, in steady flight, the model could often be controlled by less than the maximum available rolling effectiveness.

FLIGHT-TEST RESULTS AND DISCUSSION

The pilot's qualitative ratings of the controllability of the model are presented in table I for each of the lateral-control combinations

used in the flight tests. From the flight tests, a direct comparison of the controllability afforded by the two types of ailerons was obtained for the rudder-fixed condition. Aileron-control characteristics are customarily evaluated for this condition (reference 7). A direct indication of the effect of the relative time lag of the two types of ailerons was obtained in the flight tests from a comparison of the controllability produced by the flap ailerons and that produced by the plug ailerons when the rudder deflection was adjusted to make the static yawing moments equal for the two types of ailerons.

Plug Ailerons

The controllability ratings of table I show that, with the plug ailerons alone, the lateral control characteristics of the model were considered satisfactory over the lift-coefficient range covered in the flight tests except at the stall. Adverse yawing was evident at all lift coefficients except 1.0 and increased with increasing lift coefficient (fig. 5). Since the rolling moments caused by the plug ailerons also increased with increase in lift coefficient, however, the reduction in rolling effectiveness caused by the adverse yawing was approximately canceled so that the effectiveness of the plug ailerons was about the same at all angles of attack. The controllability became less satisfactory as the lift coefficient increased from 1.7 to the stall because the adverse yaw caused by the plug ailerons did become large enough to reduce seriously the rolling effectiveness. When the rudder was used in conjunction with the plug ailerons to make the yawing moments zero, the controllability of the model was satisfactory at all lift coefficients and at the stall. Control with plug ailerons was completely satisfactory throughout almost the entire lift-coefficient range covered in the investigation despite the fact that the time-lag characteristics were unsatisfactory according to the flying-qualities requirements of reference 7. This apparent discrepancy may be attributed, at least partly, to the unusual variation of rolling acceleration with time for the plug ailerons. About one-half the maximum rolling acceleration was obtained as soon as the ailerons were deflected even though maximum acceleration was not reached until much later (fig. 7). The unusual variation of rolling acceleration with time may represent the true characteristics of the control and flap configuration or it may have resulted from the very small scale of the model. Full-scale lag tests of plug ailerons with full-span flaps therefore seem desirable.

Flap Ailerons

The controllability ratings of table I show that, with the flap ailerons alone at a deflection which gave rolling moments equal to those of the plug ailerons, the lateral control characteristics of the model

were considered satisfactory at a lift coefficient of 1.0 and poor at a lift coefficient of 1.25, and the model was unflyable at lift coefficients of 1.5 or greater. The fact that the controllability with flap ailerons alone was generally unsatisfactory was attributed primarily to the very large aileron yawing moments which were adverse at all lift coefficients and became increasingly adverse as the lift coefficient increased (fig. 8). At the lowest lift coefficient ($C_L = 1.0$) the adverse yawing due to aileron deflection was insufficient to cause a substantial decrease in the rolling effectiveness of the ailerons, but at the high lift coefficients the adverse yawing caused the rolling effectiveness to be greatly reduced. This analysis is substantiated by the data of table I for the case in which the yawing moments of the aileron and rudder combinations were adjusted to zero. These data show that, when no adverse yawing moment accompanied aileron deflection, control by flap ailerons was satisfactory through the entire lift-coefficient range.

The results are presented in table I for flight tests in which the maximum total flap-aileron deflection was held constant at a value of 30° for all lift coefficients. These results show that the controllability of the model was satisfactory through the entire speed range when the yawing moment was zero. When the rudder was not used to counteract the adverse yawing of the ailerons, however, the controllability was unsatisfactory at lift coefficients of 1.5 or greater.

Comparison of Plug and Flap Ailerons

Comparison of the controllability ratings of table I shows that, with ailerons alone, the controllability was more satisfactory with plug ailerons than with flap ailerons at all flight lift coefficients. This characteristic results from the fact that the loss in rolling effectiveness due to adverse yawing was much greater for the flap ailerons than for the plug ailerons. When the yawing moments with both aileron controls were made equal by use of the rudder, the controllability of the model was generally satisfactory and was about the same with either control.

EFFECTS OF WING INCIDENCE ON OSCILLATORY STABILITY

During some of the early flight tests of the present investigation, for which the angle of incidence of the wing was -5° , a very lightly damped lateral oscillation was evident. When the model was controlled with either plug ailerons alone or flap ailerons and rudder, the oscillation was excited and the controllability was not as satisfactory as when the model had better stability (-10° wing incidence). When the

model was controlled with flap ailerons alone, however, the oscillation was not excited and the controllability was more satisfactory than when the model had the -10° wing incidence. These effects resulted in the flap ailerons alone being a better control than either the plug ailerons alone or the flap ailerons and rudder up to a lift coefficient of 1.7. This effect of stability on controllability is discussed in reference 8 where it is pointed out that in certain cases of low oscillatory stability the controls can reduce the apparent stability when the rudder is operated in such a manner as to prevent yawing. The oscillation can be avoided by operating the rudder to produce sideslip opposing the roll or, as was the case in the present investigation, by holding the rudder neutral and allowing the adverse aileron yawing moments to produce sideslip opposing the roll.

In order to increase the damping of the lateral oscillation so that the low oscillatory stability of the model would not influence the pilot's opinion of the controllability, the wing incidence was changed to -10° . This increase in negative incidence effectively increased the angle of attack of the principal longitudinal axis of inertia and, consequently, caused an increase in the stability of the lateral oscillation. This effect is discussed in detail in references 9 and 10.

CONCLUSIONS

The following conclusions were drawn from a free-flight-tunnel investigation made to obtain a comparison of the lateral controllability with conventional flap and step plug ailerons on a sweptback-wing model having full-span flaps:

1. For flights with -10° wing incidence (during which the oscillatory (Dutch roll) stability was adequate), the following conclusions apply:

(a) Plug-aileron-alone control was much more satisfactory than flap-aileron-alone control because of the loss of rolling effectiveness caused by the large adverse yawing moments produced by the flap ailerons.

(b) When the rudder was used to minimize the yawing caused by aileron deflection, the controllability of the model was satisfactory with either flap or plug ailerons.

(c) Although the time lag of the plug ailerons was excessive according to the flying-qualities requirements, the pilot's opinion was that the plug ailerons afforded a satisfactory control for the model.

2. For the flights with -5° wing incidence (during which the oscillatory (Dutch roll) stability was inadequate), the flap ailerons

alone afforded a better control than either plug ailerons alone or flap ailerons and rudder up to a lift coefficient of 1.7, apparently because the lightly damped oscillation was more easily excited by controls when the adverse yawing moment was reduced.

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National Advisory Committee for Aeronautics

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TABLE I
 QUALITATIVE RATINGS OF LATERAL CONTROL CHARACTERISTICS OF
 MODEL WITH VARIOUS COMBINATIONS OF LATERAL CONTROLS

Controllability ¹								
Lift coef- ficient	$(C_{l_{flap}})_{\max} = (C_{l_{plug}})_{\max}$				$\delta_{a_{flap}} = 30^\circ$		Ailerons and rudder ($C_{n_{flap}} = 0$)	
	Ailerons alone		Ailerons and rudder		Ailerons alone			
			$C_{n_{flap}} = C_{n_{plug}}$	$C_{n_{flap}} = 0 = C_{n_{plug}}$				
	Plug ailerons		Flap ailerons	Flap ailerons	Flap ailerons	Plug ailerons		
	1.0	A	A	A	A	A		A
1.25	A	C	A	A	A	A		
1.5	A	D	A	A	A	D		
1.71	B	D	B	B	B	D		
1.85	B	D	B	B	B	D		
Stall	C	D	B	B	B	-		

¹Controllability ratings:

A Good } Satisfactory
 B Fair }
 C Poor } Unsatisfactory
 D Uncontrollable }



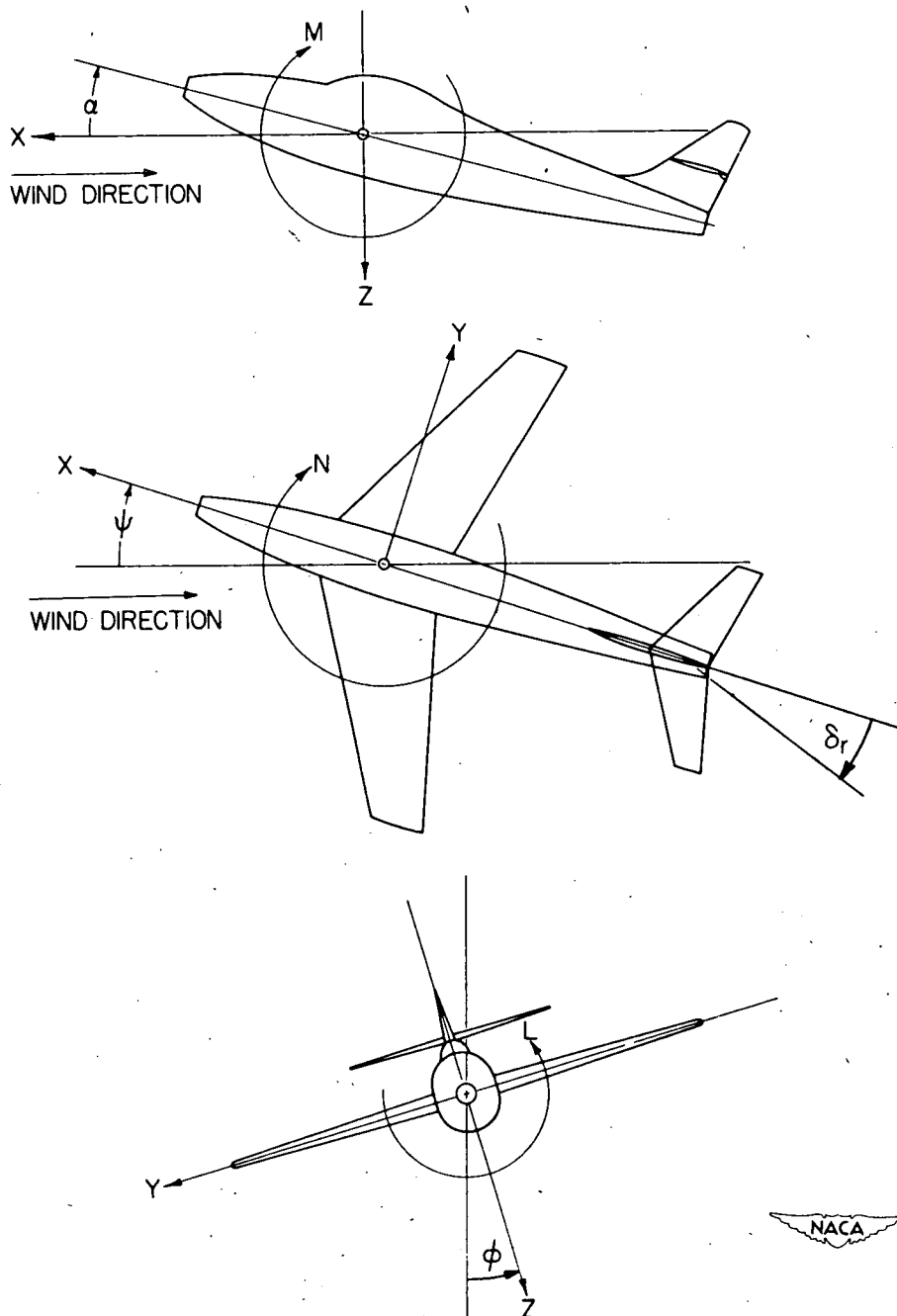


Figure 1.- The stability system of axes. Arrows indicate positive directions of moments, forces, and control-surface deflections. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wing, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

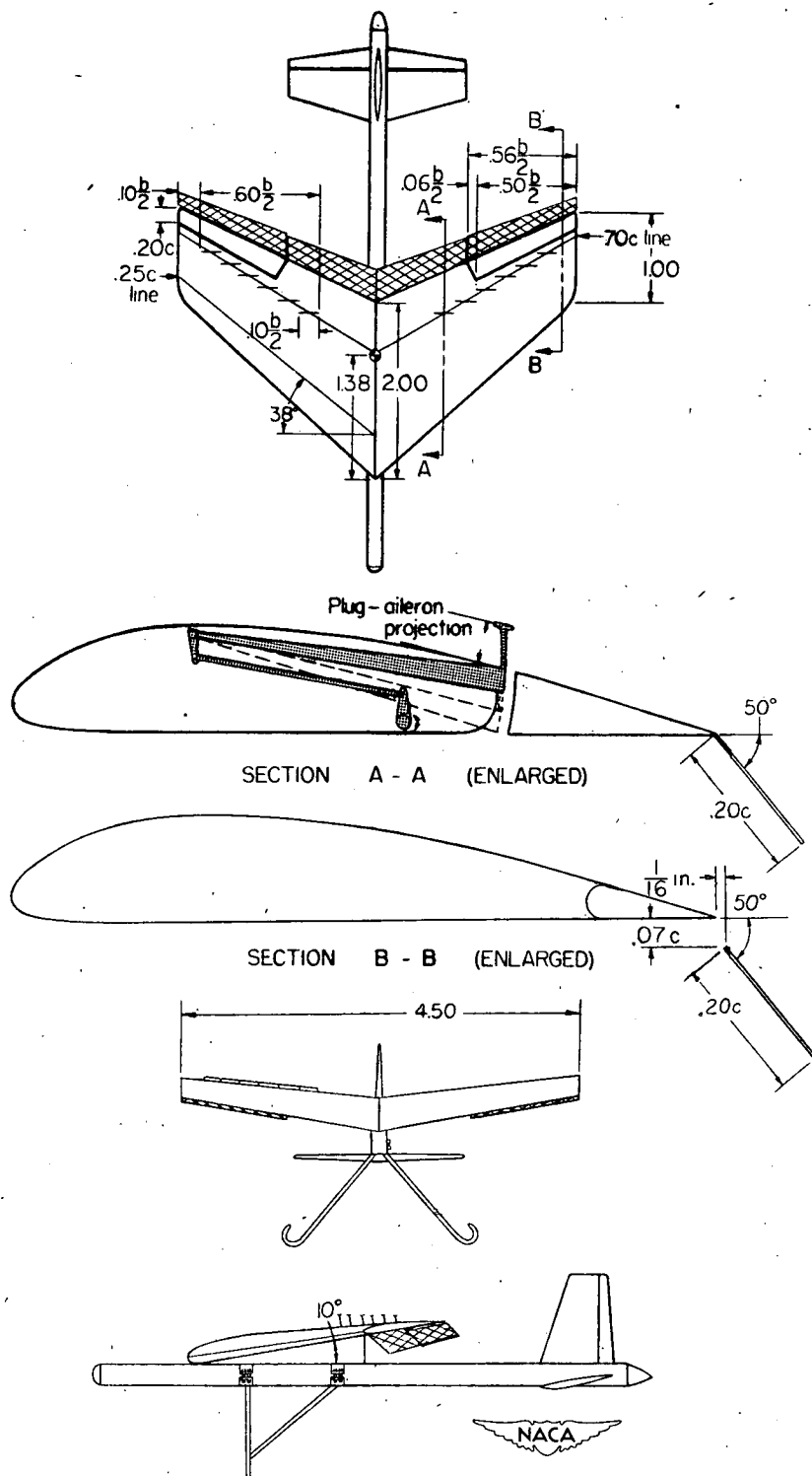


Figure 2.- Three-view sketch of free-flight-tunnel model and cross section of wing showing details of plug ailerons. All dimensions are in feet unless otherwise specified.

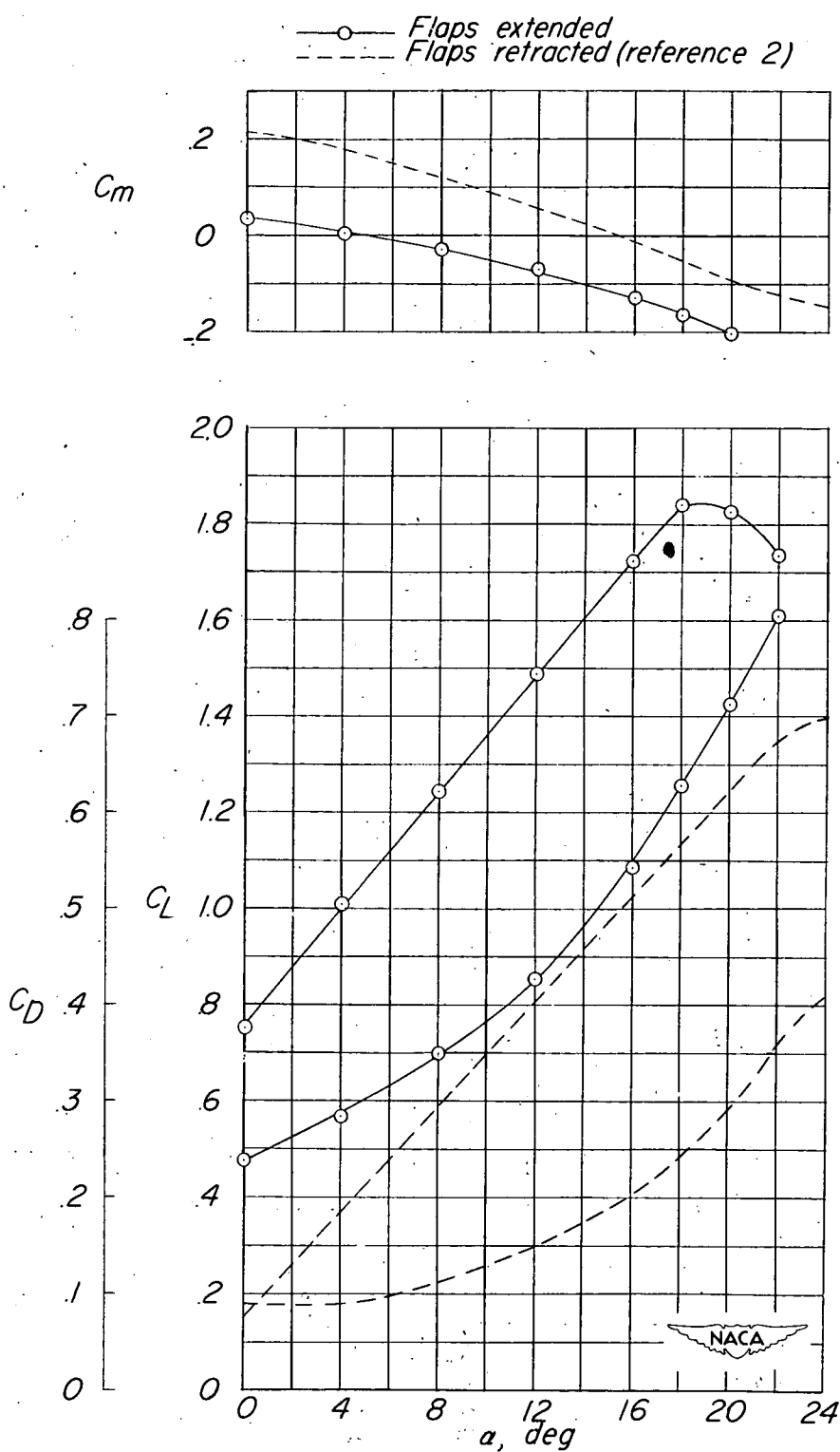


Figure 3.- Lift, drag, and pitching-moment characteristics of the model with all controls neutral.

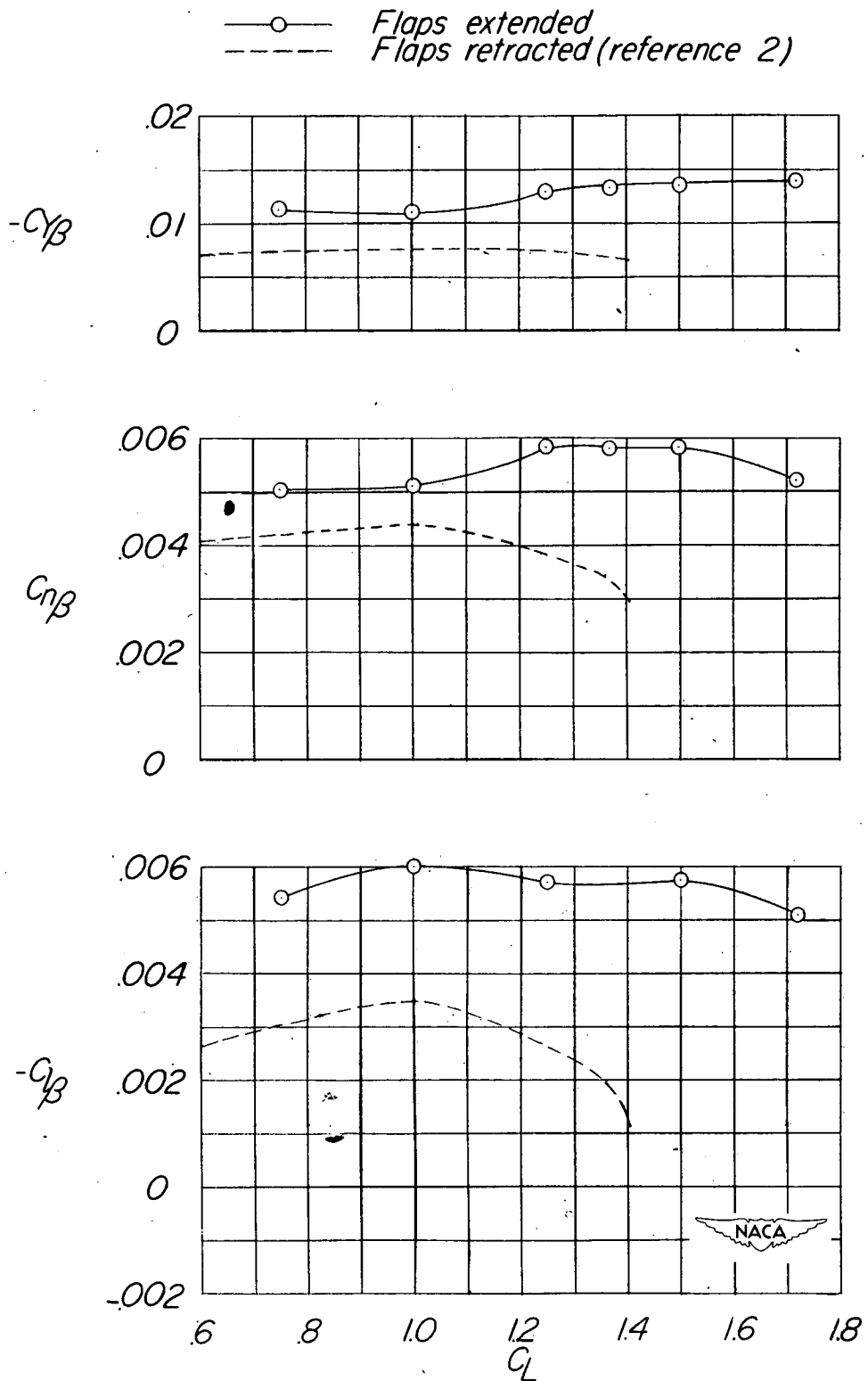


Figure 4.- Lateral stability characteristics of the model with all controls neutral.

—○— *Flaps extended*
- - - *Flaps retracted (reference 2)*

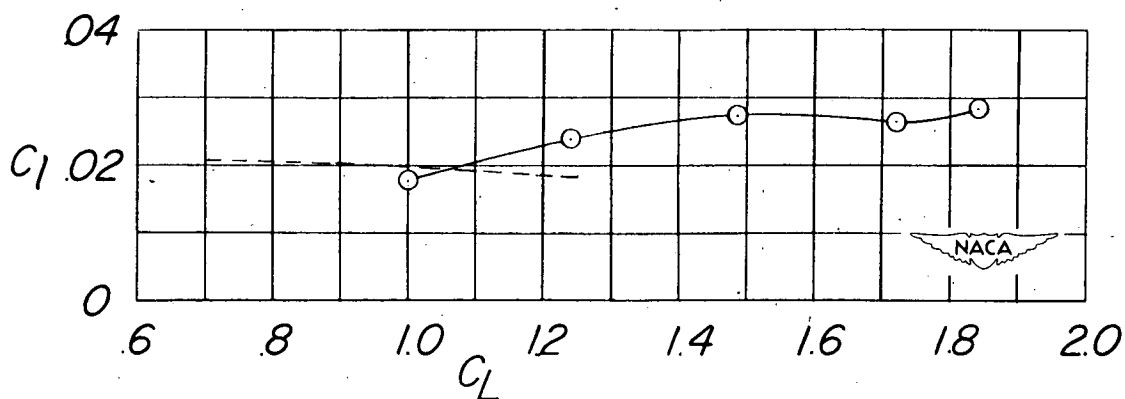
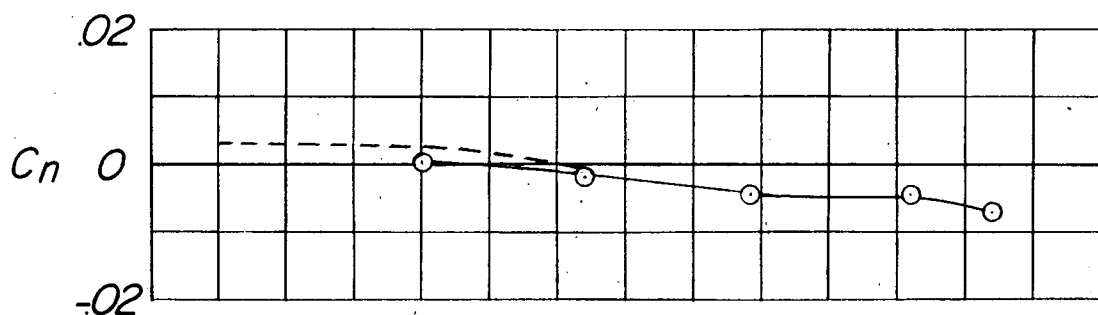
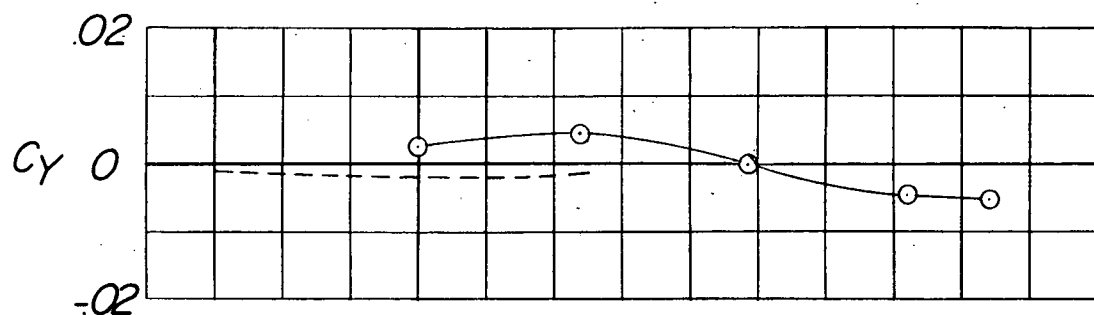


Figure 5.- Lateral control characteristics of the model with plug ailerons at maximum projection (0.06 chord).

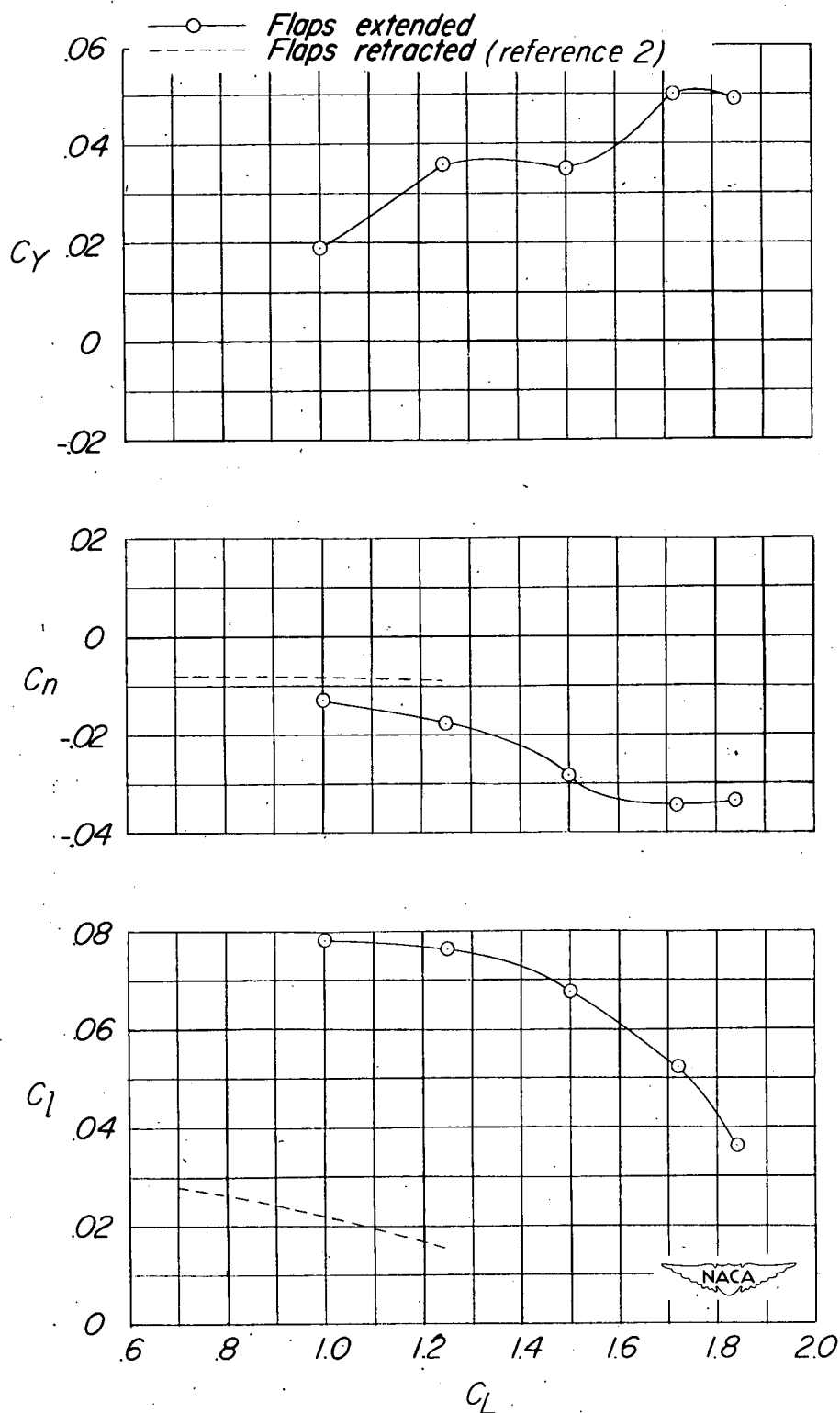


Figure 6.- Lateral control characteristics of the model with flap ailerons deflected 40° (up 20° and down 20°).

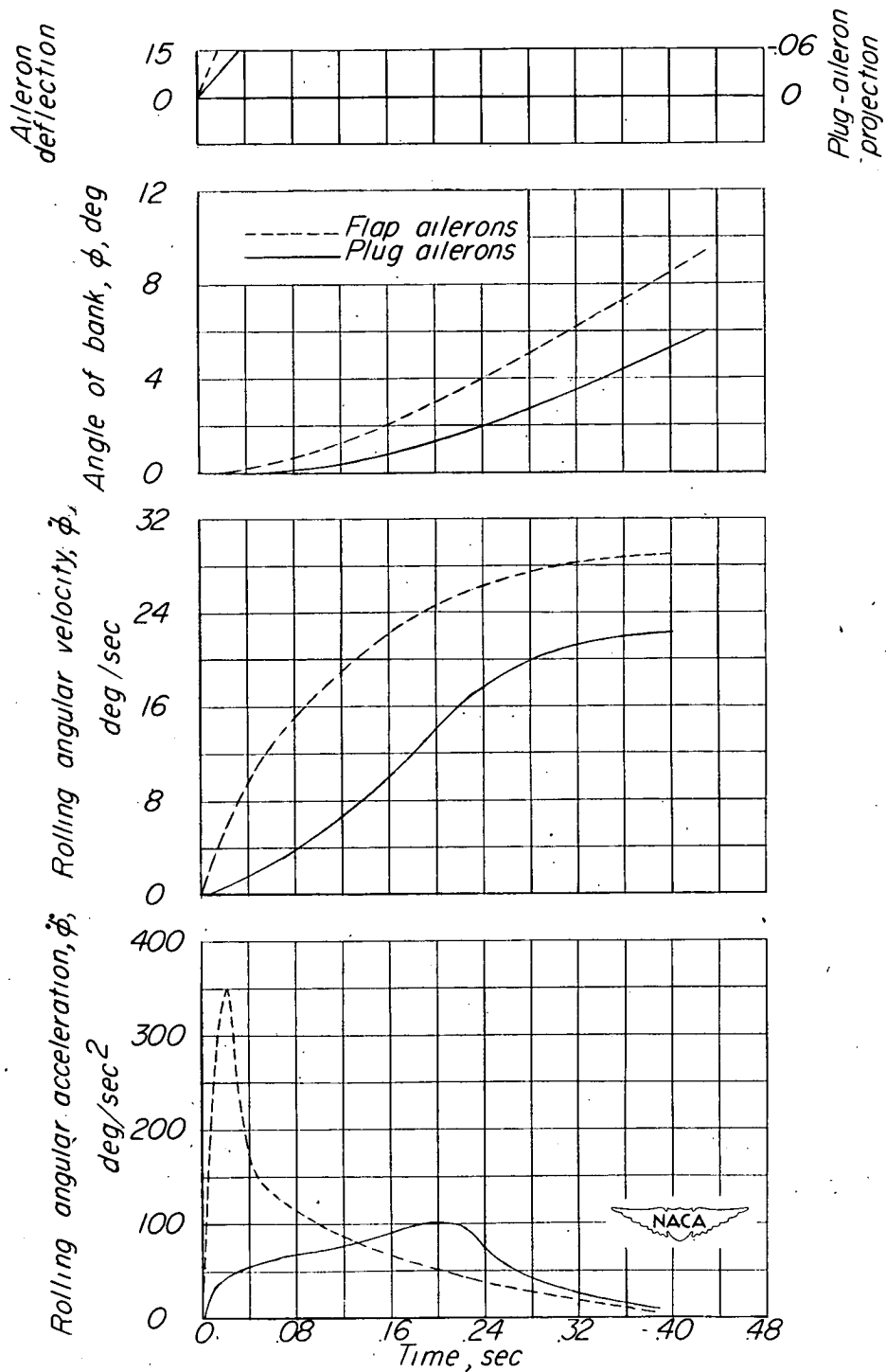


Figure 7.- Time histories of the angle of bank, rolling velocity, and rolling acceleration of the model due to aileron deflection. $C_L = 1.37$; $\delta_{a\text{flap}} = 15^\circ$; $\delta_{a\text{plug}} = -0.06c$; $\delta_r = 0^\circ$.

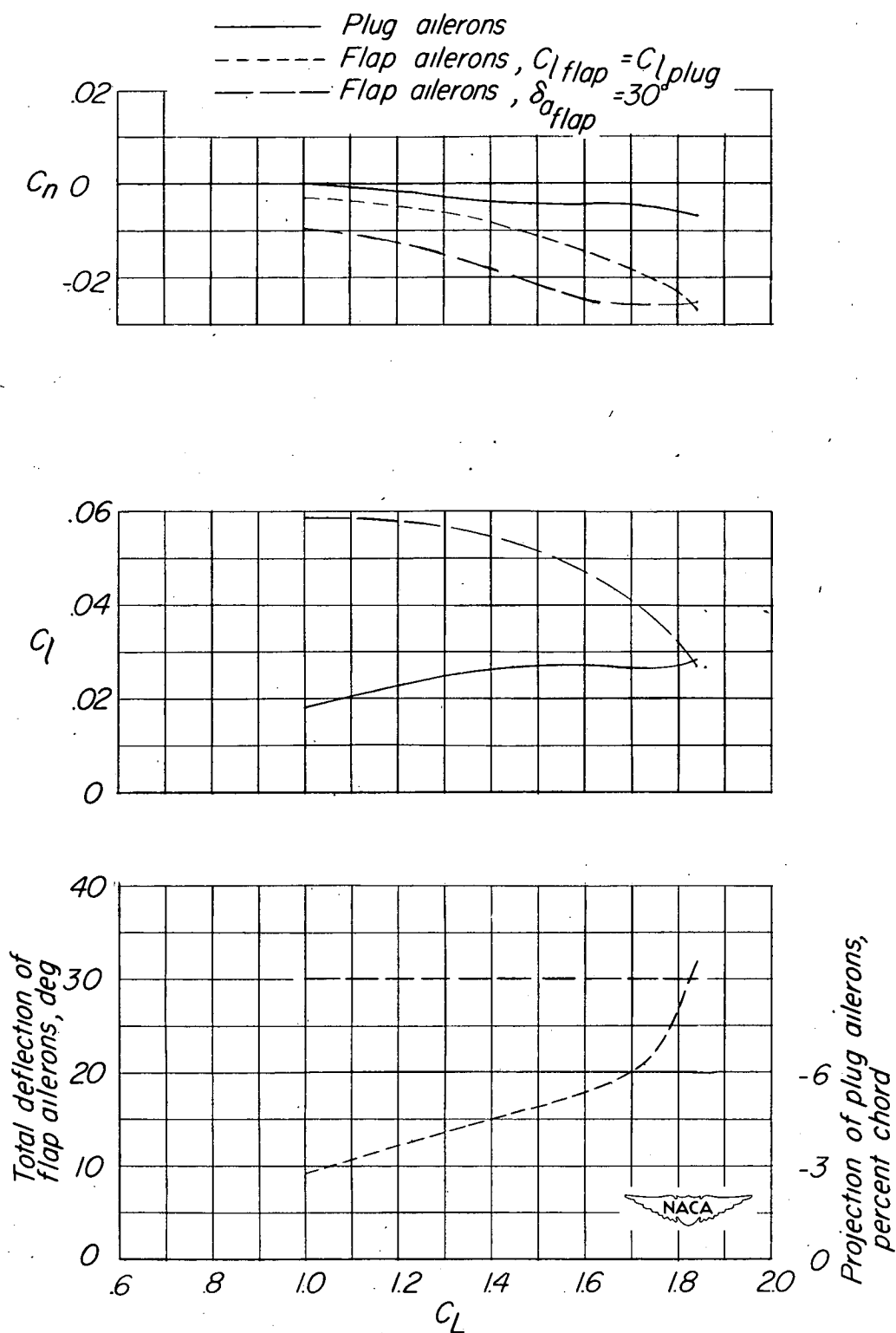


Figure 8.- Aileron deflections used in flight tests and rolling and yawing moments corresponding to these deflections.